Concentrations and inventories of $^{137}$Cs in dated sediments sampled in the Swedish Marine Environmental Monitoring Program

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Swedish Marine Environmental Monitoring Program
- aimed to study trends in pollutions

Sampling
- SGU ship, Ocean Surveyor
- Gemini sediment corer used
- 7 double cores at each station
Samples collected 2008

• SGU collected and freeze-dried the sediments
• SSM contracted DTU NUTECH in Denmark to measure selected sediment layers for their content of 137Cs, 210Pb and 208Tl
• SSM analyzed the results and performed the dating of the cores
Sediment dating

- Three independent models were used
- Cs-137 time marker in the sediment profile (Chernobyl peak assumed to represent the year 1986)
- Pb-210 sediment model (assuming constant flux and initial concentration of Pb-210)
- Th-228 sediment model (where sedimentation rate was high, assuming constant flux and initial concentration of Th-228)
Sediment model, Pb-210
(assuming constant flux and concentration of Pb-210)

- Pb-210 sediment model (assuming constant flux and initial concentration of Pb-210):
  - \( A(x) = A_0 \exp(-\lambda * x / \text{sed. rate}) + \text{Pb}_{\text{sup}} \)
- Using nonlinear least-squares fitting (nls) in the program R
- Fitted initial conc., \( A_0 \), sedimentation rate and supported Pb-210
- Advantage: easy and fast method, nls fit provides statistic on the fitted parameters

Ex. Pb (at x=0), \( A_0 = 822.6 \pm 37.1 \) Bq/kg
Sedimentation rate = 0.16 +/- 0.01 cm/y
Supported Pb = 60.4 +/- 12.8 Bq/kg
Cs-137 Sedimentation rate = 0.14 +/- 0.05 cm/y
Sediment model, Th-228
(assuming constant flux and initial concentration of Th-228)

- Th-228 ($t_{1/2} = 1.9$ y) determined from its daughter Tl-208
- Th-228 sediment model (assuming constant flux and initial concentration of Th-228):
  - $A(x)=A_0 \exp(-\lambda \cdot x / \text{sed.rate}) + \text{Th}_{\text{sup}}$
- Using nonlinear least-squares fitting in R
- Fitted $A_0$, sedimentation rate and supported Th-228
- Advantage: can be used where sedimentation is high (over 1cm/y)
Results: Bothnian Bay and Bothnian Sea

- Ex. Pb (at x=0), $A_0 = 548.9 \pm 40.4$ Bq/kg
  - Sedimentation rate = 0.18 \pm 0.04 cm/y
  - Supported Pb = 27.6 \pm 27.7 Bq/kg
- Cs-137 Sedimentation rate = 0.18 \pm 0.05 cm/y

- Ex. Pb (at x=0), $A_0 = 822.6 \pm 37.1$ Bq/kg
  - Sedimentation rate = 0.16 \pm 0.01 cm/y
  - Supported Pb = 60.4 \pm 12.8 Bq/kg
- Cs-137 Sedimentation rate = 0.14 \pm 0.05 cm/y
  - Note: Cs-137 act is divide by 5

- Ex. Pb (at x=0), $A_0 = 254.2 \pm 17.6$ Bq/kg
  - Sedimentation rate = 0.67 \pm 0.12 cm/y
  - Supported Pb = 128.7 \pm 13.7 Bq/kg
- Cs-137 Sedimentation rate = 0.66 \pm 0.09 cm/y
  - Note: Cs-137 act is divide by 5

- Ex. Pb (at x=0), $A_0 = 369 \pm 16.1$ Bq/kg
  - Sedimentation rate = 0.37 \pm 0.04 cm/y
  - Supported Pb = 47.1 \pm 9.9 Bq/kg
- Cs-137 Sedimentation rate = 0.39 \pm 0.09 cm/y
  - Note: Cs-137 act is divide by 5

- Ex. Pb (at x=0), $A_0 = 260.9 \pm 13.4$ Bq/kg
  - Sedimentation rate = 0.42 \pm 0.05 cm/y
  - Supported Pb = 138.2 \pm 9.6 Bq/kg
- Cs-137 Sedimentation rate = 0.39 \pm 0.09 cm/y
  - Note: Cs-137 act is divide by 5
Results Baltic Proper

Ex. Pb (at x=0), A0 = 896.5 ± 33.6 Bq/kg
Sedimentation rate = 0.88 ± 0.09 cm/y
Supported Pb = 99.2 ± 16 Bq/kg
Cs-137 Sedimentation rate = 0.75 ± 0.09 cm/y

Ex. Pb (at x=0), A0 = 835.2 ± 122.6 Bq/kg
Sedimentation rate = 1.03 ± 0.37 cm/y
Supported Pb = 38.8 ± 94.6 Bq/kg
Cs-137 Sedimentation rate = 0.93 ± 0.09 cm/y

Ex. Pb (at x=0), A0 = 1155.9 ± 100.5 Bq/kg
Sedimentation rate = 0.08 ± 0.01 cm/y
Supported Pb = 60.9 ± 28.4 Bq/kg
Cs-137 Sedimentation rate = 0.02 ± 0.05 cm/y

Ex. Pb (at x=0), A0 = 677.6 ± 116.6 Bq/kg
Sedimentation rate = 1.03 ± 0.42 cm/y
Supported Pb = 93.7 ± 85.5 Bq/kg
Cs-137 Sedimentation rate = 1.02 ± 0.09 cm/y

Ex. Pb (at x=0), A0 = 776.9 ± 38.3 Bq/kg
Sedimentation rate = 0.045 ± 0.003 cm/y
Supported Pb = 88.8 ± 5.8 Bq/kg
Cs-137 Sedimentation rate = 0.02 ± 0.05 cm/y
Results:
Southern Baltic Proper, Kattegat and Skagerrak

Ex.Pb (at x=0), A0 = 308.8 ± 35.5 Bq/kg
Sedimentation rate = 0.358 ± 0.086 cm/y
Supported Pb = 48.4 ± 19 Bq/kg
Cs-137 Sedimentation rate = 0.27 ± 0.04 cm/y

Ex.Pb (at x=0), A0 = 75.4 ± 8.2 Bq/kg
Sedimentation rate = 0.62 ± 0.15 cm/y
Supported Pb = 16 ± 5 Bq/kg
Cs-137 Sedimentation rate = 0.66 ± 0.09 cm/y

Note: Cs-137 act. is multiplied by 10

Note: Cs-137 act is multiplied by 5

Note: Cs-137 act is multiplied by 10
### Sedimentation rates

<table>
<thead>
<tr>
<th>Station</th>
<th>Pb-210 sed. rate [cm/y] ± 1 SD</th>
<th>Th-228 sed. rate [cm/y] ± 1 SD</th>
<th>Cs-137 sed. rate [cm/år] ± 1 SD</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE-17</td>
<td>0.18 ± 0.04</td>
<td></td>
<td>0.18 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>SE-1</td>
<td>0.16 ± 0.01</td>
<td></td>
<td>0.14 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>SE-2</td>
<td>0.67 ± 0.12</td>
<td>0.78 ± 0.22</td>
<td>0.66 ± 0.09</td>
<td>Used Ra-226 activity as support level</td>
</tr>
<tr>
<td>SE-3</td>
<td>0.37 ± 0.04</td>
<td></td>
<td>0.39 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>SE-4</td>
<td>0.42 ± 0.05</td>
<td>0.83 ± 0.34</td>
<td>0.39 ± 0.09</td>
<td>Probably Cs-137 peak at 9.5 cm slice (NA)</td>
</tr>
<tr>
<td>SE-5</td>
<td>1.03 ± 0.37</td>
<td>1.56 ± 0.14</td>
<td>0.93 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>SE-6</td>
<td>0.88 ± 0.09</td>
<td>1.49 ± 0.30</td>
<td>0.75 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>SE-7</td>
<td>0.08 ± 0.01</td>
<td></td>
<td>0.02 ± 0.05</td>
<td>Difficult to determine Cs-137 sed. rate</td>
</tr>
<tr>
<td>SE-8</td>
<td>1.03 ± 0.42</td>
<td>2.13 ± 0.97</td>
<td>1.02 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>SE-9</td>
<td>0.045 ± 0.003</td>
<td></td>
<td>0.02 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>SE-10</td>
<td>0.047 ± 0.002</td>
<td></td>
<td></td>
<td>Pb-210 sed. rate determined under mixing zon</td>
</tr>
<tr>
<td>SE-11</td>
<td>0.36 ± 0.09</td>
<td></td>
<td>0.27 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>SE-12</td>
<td>0.57 ± 0.25</td>
<td></td>
<td>0.56 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>SE-13</td>
<td>0.62 ± 0.15</td>
<td></td>
<td>0.66 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>SE-15</td>
<td></td>
<td></td>
<td></td>
<td>Mixed to at least 25 cm or an very high sed. rate</td>
</tr>
<tr>
<td>SE-16</td>
<td>1.49 ± 0.95</td>
<td>1.5 ± 0.3</td>
<td>&gt;1</td>
<td>Difficult to determine Cs-137 sed. rate</td>
</tr>
</tbody>
</table>
## Inventories

<table>
<thead>
<tr>
<th>Station</th>
<th>Cs-137 inventory 2008</th>
<th>Cs-137 inventory 2003</th>
<th>Cs-137 added between 2003-2008, derived from sed. rate</th>
<th>net change over the 5 years</th>
<th>Cs-137 added between 2003-2008 in percent</th>
<th>Cs-137 decayed between 2003-2008 in percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE-17</td>
<td>5.2</td>
<td>5.5</td>
<td>473</td>
<td>decreasing</td>
<td>10.0</td>
<td>10.9</td>
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<tr>
<td>SE-1</td>
<td>10.3</td>
<td>11.3</td>
<td>722</td>
<td>decreasing</td>
<td>7.5</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-2</td>
<td>52.8</td>
<td>76.5</td>
<td>4550</td>
<td>decreasing</td>
<td>9.4</td>
<td>10.9</td>
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<tr>
<td>SE-3</td>
<td>44.4</td>
<td>55.8</td>
<td>3556</td>
<td>decreasing</td>
<td>8.7</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-4</td>
<td>24.2</td>
<td>22.7</td>
<td>2261</td>
<td>decreasing</td>
<td>10.2</td>
<td>10.9</td>
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<tr>
<td>SE-5</td>
<td>3.6*</td>
<td>4.6</td>
<td>284</td>
<td>decreasing</td>
<td>8.6</td>
<td>10.9</td>
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<tr>
<td>SE-6</td>
<td>2.7</td>
<td>3.5</td>
<td>244</td>
<td>decreasing</td>
<td>9.7</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-7</td>
<td>0.65*</td>
<td>1.0</td>
<td>40</td>
<td>decreasing</td>
<td>6.6</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-8</td>
<td>2.6*</td>
<td>4.8</td>
<td>180</td>
<td>decreasing</td>
<td>7.5</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-9</td>
<td>0.79</td>
<td>1.1</td>
<td>55</td>
<td>decreasing</td>
<td>7.5</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-10</td>
<td>1.2</td>
<td>2.9</td>
<td>73</td>
<td>decreasing</td>
<td>6.4</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-11**</td>
<td>3.0</td>
<td>1.3</td>
<td>328</td>
<td>increasing</td>
<td>12.2</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-12</td>
<td>3.7</td>
<td>2.6</td>
<td>292</td>
<td>decreasing</td>
<td>8.6</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-13</td>
<td>0.92</td>
<td>0.82</td>
<td>95</td>
<td>increasing</td>
<td>11.5</td>
<td>10.9</td>
</tr>
<tr>
<td>SE-15</td>
<td>1.2*</td>
<td>1.1</td>
<td>0</td>
<td>increasing</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>SE-16</td>
<td>0.98*</td>
<td>3.0</td>
<td>246</td>
<td>increasing</td>
<td>32.7</td>
<td>10.9</td>
</tr>
</tbody>
</table>

* some activity might be missing due to limited sample depth

** sample station has been moved approx 20km to the east
Conclusions

• Good agreement between independent sediment dating techniques

• Highest sedimentation rate at the western stations (> 1 cm/y) and lowest at the south-east, west and south-west of Gotland (< 1mm/y)

• Cs-137 concentrations in surface sediment (0-1 cm) has a decreasing time trend at all stations (4-7 Bq/kg West Coast, 40-100 Bq/kg South Coast, 110-250 Bq/kg Baltic Proper, 250-830 Bq/kg Bothnian Bay and Bothnian Sea)

• Cs-137 inventory at 2008 has decreased about 1-3 % since 2003 at most of the stations